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Evaluation of KTJT-1, an early-maturity mutant of sweet sorghum acquired by carbon ions irradiation*

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Sweet sorghum has the potential of becoming a useful energy crop. An early-maturity mutant of sweet sorghum, KFJT-1, was obtained by carbon ions irradiation of KFJT-CK, a wild plant. In this paper, we evaluate the mutant from the length and fresh weight of radicle and leaves after seed germination, the growth rate at the elongation stage, and the internodal parameters under field trail condition. The results showed that the seedling growth of KFJT-1 was inhibited by carbon ions irradiation, and the leaf length, the fresh weight of radicle and leaves from KFJT-1 decreased by 15.32%, 76.27%, and 27.08% than those of KFJT-CK, respectively. However, the growth rate of KFJT-1 on July 12, July 27 and August 1 increased by 16.19%, 59.28% and 26.87%, respectively, compared with the KFJT-CK. The stalk diameter, total biomass yield and sugar content of KFJT-1 was higher than those of KFJT-CK, despite that the plant height of KFJT-1 was significantly less than KFJT-CK ($P < 0.05$). In addition, KFJT-1 differed from KFJT-CK in the internodal length, weight and sugar content. In conclusion, the early-maturity mutant of KFJT-1 will be a promising variety for sweet sorghum industrialization in Gansu province, China.

Keywords: Sweet sorghum, Early maturity, Carbon ions, Evaluation

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I. INTRODUCTION

An increased concern over security of the oil supply and the negative impact of fossil fuels on the environment poses a pressure of finding renewable fuel alternatives [1]. In recent years, growing attention has been devoted to converting biomass into fuel ethanol, which is considered the cleanest liquid fuel alternative to fossil fuels [2]. As feedstock for fuel ethanol, sweet sorghum [*Sorghum bicolor* (*L.*) Moench] is a high biomass- and sugar-yielding crop with high photosynthetic efficiency [3], and has the potential of becoming a useful energy crop [4–7]. However, high quality raw materials are the focus and life line of sweet sorghum industrialization. In fact, the scarcity of excellent varieties of sweet sorghum inhibits sustainable development of its industrialization.

Ion beam, as a new source of mutation, has been characterized by a higher mutation rate and wider mutational spectrum with lower damage of the irradiated organism, hence the wide use of ion beam mutation technology for breeding crops in agricultural production [8]. In breeding practices, plant breeders seek high production, high quality, and high adversity- resistant varieties. Some of mutants induced by ions may have been applied directly for production [9]. At Institute of Modern Physics (IMP), Chinese Academy of Sciences, the practice of heavy ion plant breeding includes various crops of wheat, corn, vegetable, herbage and flower, and antibiotics. One of the heavy-ion improved wheat varieties has been planted on a large scale in local regions after a strict authentication. Many favorable flower mutants after heavy-ion irradiation were acquired as well [10].

In answering China's strategy demand on energy, IMP has devoted to the industrialization of bioethanol from sweet sorghum since 2006, using the Heavy Ion Research Facility in Lanzhou (HIRFL) for variety improvement of sweet sorghum with mutation breeding technology [11, 12]. An early maturity mutant, KFJT-1, has been selected at 80 Gy dose, with the growth period of about 20 days shorter than that of KFJT-CK, a wild plant. Nowadays, KFJT-1 has been planted for M5 generations in Gansu and Hainan provinces, China. The latter is the southern breeding base for northern breeders. In this paper, we evaluate the KFJT-1 mutant in terms of the length and fresh weight of radicle and leaves after seeds germination, the growth rate at the elongation stage, internodal parameters under field trail condition and agronomic traits, so as to provide basic data for further regional evaluation trials and mutation mechanism research.

II. MATERIALS AND METHODS

A. Plant materials

The early maturity mutant, KFJT-1, was acquired in 2006 by irradiating KFJT-CK seeds, to 80 Gy using 100 MeV/u ^{12}C ion beams from the HIRFL at the dose of about 20 Gy min^{-1}.

B. Trial site and design

In 2008 and 2009, the field trials of KFJT-1 and KFJT-CK were conducted at botany garden of Lanzhou Univer-

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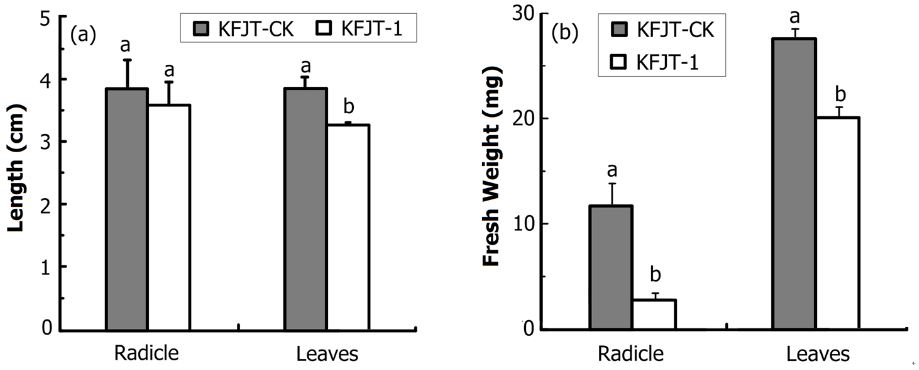

Fig. 1. The length (a) and fresh weight (b) of radicle and leaves from KFJT-1 and KFJT-CK. The histograms labeled with the same letter did not differ significantly ($P > 0.05$) by Duncan's multiple range test.

sity (36°40′ N, 103°49′ E; 1520 m height above sea level), Gansu province, China. In the experiments, each variety was planted under plastic film mulching cultivation and the plot size was adopted to 25 m^2 (5 m × 5 m bed comprising five rows). The spacing was 50 cm between ridges and 24 cm between plants.

C. Sampling and measure

For length and fresh weight of radicle and leaves, seeds of KFJT-1 and KFJT-CK were sterilized for 10 min in 0.1% HgCl solution, and washed 5 times with sterilized water. When germinating, 100 grains seeds of equal size without moldy and lesion were selected from KFJT-1 and KFJT-CK, respectively. Where after, the germinating seeds were placed in a 90 mm Petri dish containing double-layer wet filter paper, and germinated at (25 ± 2) °C in a growth chamber under a 16-h photoperiod provided by fluorescent light tubes (50 µmol m^{-2} s^{-1}). After germinating for 7 days, 10 plants were chosen from each Petri dish to measure the length and fresh weight of radicle and leaves. In the velocity of growth at elongation stage, the plant height was measured on fixed 8 plants of KFJT-1 and KFJT- CK every five days from July 7 to August 1. For internodal parameters, five plants was sampled according to method of random. When matured, the internodal parameters were measured, including length, weight, sugar content of different internodes.

D. Statistical analysis

All statistic analyses were conducted using SPSS 13.0 software. The data, at least in triplicates ($n \geq 3$), were expressed as means ± standard deviation. To assess the statistical significance of the treatment differences, a one-way analysis of variance (ANOVA) followed by Duncan's multiple range test ($P < 0.05$) was employed. Figures were plotted with Origin 7.5 software.

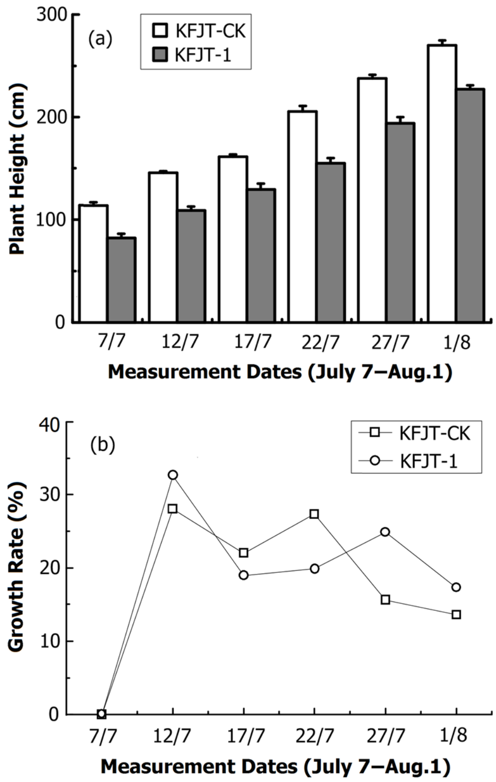

Fig. 2. (a) Height and (b) the velocity of growth of KFJT-1 and KJFT-CK during elongation stage.

III. RESULTS AND DISCUSSION

A. Length and fresh weight of radicle and leaves

Figure 1 shows that, in comparison to KFJT-CK, the seedling growth of KFJT-1 was inhibited by carbon ions irradiation, which resembled previous studies [12, 14, 15]. Although KFJT-1 did not differ significantly from KFJT-CK in the length of radicle ($P < 0.05$), dramatic radiation effects were observed on the leaf length (Fig. 1(a)) and fresh weight

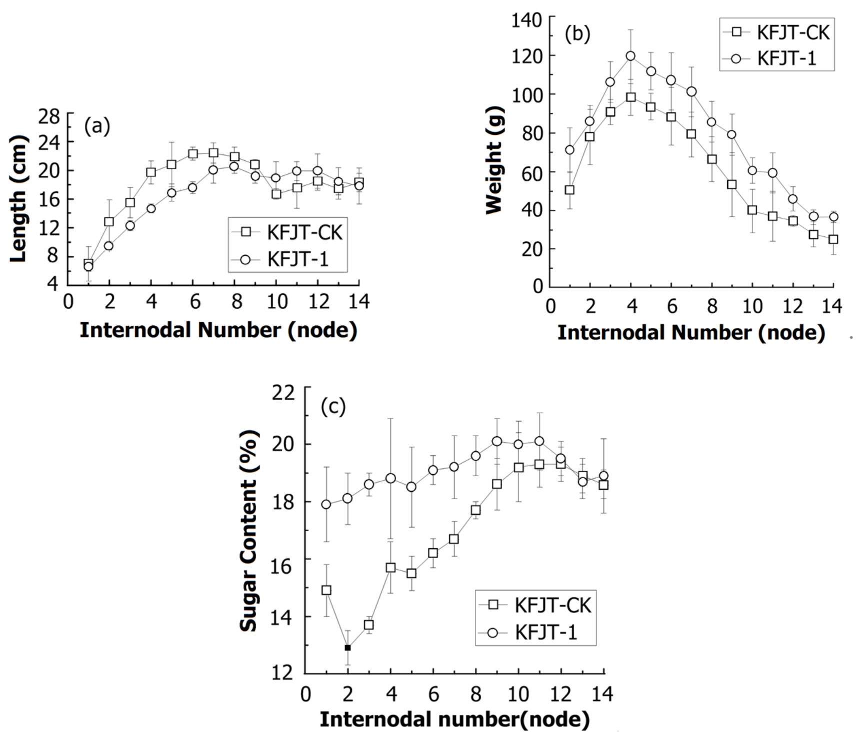

Fig. 3. Internodal parameters of KFJT-1 and KFJT-CK, (a) internodal length, (b) internodal weight and (c) internodal sugar content at harvest period.

TABLE 1. The plant height, stalk diameter, total biomass yield and sugar content of KFJT-1 and KFJT-CK

Variety	Plant height (cm)	Stalk diameter (mm)	Total biomass yield (t ha^{-1})	Sugar content (%)
KFJT-CK	336±6.55	23.29±1.11	74.5±7.00	16.55±0.46
KFJT-1	259±4.64 [a]	24.22±0.15	78±3.90	17.85±0.49

[a] Significant difference for plant height between KFJT-CK and KFJT-1 at the $P < 0.05$ level.

of radicle and leaves (Fig. 1(b)) 7 days after germination. The leaf length and fresh weight of radicle and leaves from KFJT-1 were respectively 15.32%, 76.27% and 27.08% less than those of KFJT-CK. The analysis of ANOVA showed significantly difference between KFJT-1 and KFJT-CK ($P < 0.05$).

In the life cycle of a plant, seeds have the highest resistance to extreme environmental stresses, whereas seedlings are most susceptible [16].The leaf length and fresh weight of radicle and leaves of KFJT-1 were significantly inhibited because of physiological damages induced by carbon ions, being similar to the results by salinity [17].

B. Growth rate in elongation stage

The elongation stage of sweet sorghum is the key plant growth stage [18]. Our previous research indicated that the averaged growth rate reached 12 cm/day for the sweet sorghum cultivar 'Wray' on July 20–26 [19]. In this study, the plant height of KFJT-1 and KFJT-CK presented obvious rise trend during the elongation stage (Fig. 2(a)). However, the plant height of KFJT-1 was much less than those of KFJT-CK. The average height of growth every day was 6.2 cm for KFJT-CK, faster than that of KFJT-1, with the corresponding value of 5.8 cm from July 7 to August 1. Interestingly, further study found that KFJT-1 excelled KFJT-CK in growth rate on July 12 and 27, and August 1, with an increase of 16.19%, 59.28% and 26.87%, respectively (Fig. 2(b)).

C. Internodal length, weight and sugar content

The stems of KFJT-1 and KFJT-CK showed a different pattern in harvest period in their internodal length, weight and sugar content. As shown in Fig. 3(a) from the first node to the ninth node, each internodal length of KFJT-CK was significantly higher than that of KFJT-1 ($P < 0.05$), whereas each internodal length of KFJT-CK from the tenth node to the thirteenth node was less than that of KFJT-1. In Fig. 3(b), the internodal weight of KFJT-1 was obviously higher than that of KFJT-CK ($P < 0.05$), and the node weight of KFJT-1 and FKJT-CK varied similarly with the internodal number, reach-

ing the maximum internodal weight at the fourth node, being 119.3 g for KFJT-1and 98.3 g for FKJT-CK. Fig. 3(c) shows the internodal sugar content of KFJT-1 and FKJT-CK, from the first node to the tenth node, each internodal of KFJT-1 had significantly higher sugar conten than that of KFJT-CK ($P < 0.05$).

D. Stalk size, biomass yield and sugar content

The main agronomic features of KFJT-1 and KFJT-CK are given in Table 1. They include the plant height, stalk diameter, total biomass yield and sugar content . While the plant height of KFJT-1 was 22.92% less than KFJT-CK, the stalk diameter, total biomass yield and sugar content of KFJT-1 were respectively 3.99%, 4.69% and 7.85% higher than those of KFJT-CK.

Plant breeding is now based on creating variation, and the use of nuclear techniques in plant breeding has been mostly directed for inducing mutation [20]. Heavy ion beam, as a new mutagen, gives a broad variation spectrum, and the variants can be used as plant breeding materials [14]. The evaluated early-maturity mutant, KFJT-1, induced by carbon ions irradiation, is advantageous over KFJT-CK in the total biomass yield and sugar content. However, carbon ions irradiation may induce physiological damages to the sweet sorghum seeds, hence the obvious inhibition of radicle and leaves of KFJT-1 and the reduced plant height and internodal length of KFJT-1.

In conclusion, despite the shorter plant height of KFJT-1 than that of KFJT-CK, the total biomass yield of KFJT-1 increased to 78 t ha^{-1} due to the greater stalk diameter and internodal weight than KFJT-CK. And the sugar content of KFJT-1 was higher than KFJT-CK, too.

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